Particle-Hole Character of Higgs and Goldstone Modes in Strongly Interacting Lattice Bosons

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We study the low-energy excitations of the Bose-Hubbard model in the strongly-interacting superfluid phase using a Gutzwiller approach. We extract the single-particle and single-hole excitation amplitudes for each mode and report emergent mode-dependent particle-hole symmetry on specific arc-shaped lines in the phase diagram connecting the well-known Lorentz-invariant limits of the Bose-Hubbard model. By tracking the in-phase particle-hole symmetric oscillations of the order parameter, we provide an answer to the long-standing question about the fate of the pure amplitude Higgs mode away from the integer-density critical point. Furthermore, we point out that out-of-phase symmetric oscillations in the gapless Goldstone mode are responsible for a full suppression of the condensate density oscillations. Possible detection protocols are also discussed.

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